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2018-07

Huotilainen , M & Tervaniemi , M 2018 , ' Planning music-based amelioration and training in infancy and childhood based on neural evidence ' , Annals of the New York Academy of Sciences , vol. 1423 , no. 1 , pp. 146-154 . https://doi.org/10.1111/nyas.13655

http://hdl.handle.net/10138/238341
https://doi.org/10.1111/nyas.13655

Ann. N.Y. Acad. Sci. ISSN 0077-8923

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Special Issue: *The Neurosciences and Music VI*
REVIEW

Planning music-based amelioration and training in infancy and childhood based on neural evidence

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Music-based amelioration and training of the developing auditory system has a long tradition, and recent neuroscientific evidence supports using music in this manner. Here, we present the available evidence showing that various music-related activities result in positive changes in brain structure and function, becoming helpful for auditory cognitive processes in everyday life situations for individuals with typical neural development and especially for individuals with hearing, learning, attention, or other deficits that may compromise auditory processing. We also compare different types of music-based training and show how their effects have been investigated with neural methods. Finally, we take a critical position on the multitude of error sources found in amelioration and training studies and on publication bias in the field. We discuss some future improvements of these issues in the field of music-based training and their potential results at the neural and behavioral levels in infants and children for the advancement of the field and for a more complete understanding of the possibilities and significance of the training.

Keywords: brain; music; auditory; infant; child; language

Introduction

Researchers, clinicians, and teachers, as well as the families of infants and children, place high hopes on using music to ameliorate several types of weaknesses and challenges of the auditory system and on training the cognitive development of children with typical and atypical profiles. This excitement is not recent—traditionally, music has been an integral part of childcare, both for regulating the physiological status of the infant and for providing the auditory system with good material for learning. There is evidence that singing to an infant helps the infant to learn the regulation of arousal levels and attention[1] and that musical content in speaking to infants (parentese or motherese) allows the infant to extract linguistically relevant information like words[2] or statistical properties of syllables.[3] These ancient and cross-cultural habits of infant and child care, the efficacy of which has been later shown by research, form the fundamental inspiration for therapists, clinicians, and speech therapists to use music-based amelioration methods in their work. In education, there is also a long tradition of using music-based learning methods for a wide variety of subjects, either as teaching methods or as beneficial content for learning. Examples of teaching music in the context of improving academic skills date far back in history, with the first European universities in the Middle Ages counting music as one of the seven topics of the faculty of arts.[4]

Recent neuroscientific evidence related to music and the brain provides a second, present-day motivation for using music as one component of amelioration and training. Neuroscientific recordings of the effects of music during the past 2–3 decades have formed a basis for our understanding of how music affects the brain. Neuroscientists have studied changes in the brains of individuals who have actively participated in musical training (learning to play an instrument or sing). These findings have given rise to new, more specific hypotheses and suggestions as to which types of specific challenges in the auditory system of infants and children could be ameliorated, trained, and educated by using music

doi: 10.1111/nyas.13655

and which types of specific activities in music making could provide these benefits.

Here, we aim to increase our understanding of how to use the recent neuroscientific findings of the effects of music on the brain for planning evidence-based, music-enriched amelioration of the auditory system. We specifically ask the following questions. Which findings of the neuroscience of music are relevant for planning such use of music? Which types of challenges of the auditory system could be especially targeted? And is there evidence as to which types of music use these findings support as being most effective?

We also want to take a critical position on the studies so far and their error sources, including participant selection and drop-out rates and, particularly, biased dropouts. Positive effects of music-based training studies are contaminated with publication bias, and for this reason we will discuss future improvement in the field of music-based training and their potential results at the neural and behavioral levels in infants and children. Methodological advancement in the field is needed in order to accomplish a more complete understanding of the possibilities and significance of music-based training.

Neuroscientific findings inspire the use of music

The tradition of comparing musicians' and nonmusicians' brains is already several decades long and has provided the scientific community with some understanding of what differences are related to this training all the way up to the professional level, as well as soon after starting the training in childhood or even in adulthood (for reviews, see Refs. 5–7).

Structural differences in the gray matter of several cortical areas, including motor, somatosensory, and auditory areas, have been observed.[8] These differences are related to cortical folding, indicating a greater cortical surface, or longer distances between the cortical areas of, for example, fingers, again indicating that a larger patch of cortical surface is reserved for finger control compared with nonmusicians. The first, seminal studies gave evidence about larger auditory and somatosensory cortical areas in adult musicians compared with nonmusicians.[9,10] Some findings are related to gray matter density, possibly implying a larger number of neurons in the same voxel of brain tissue. In addition, some studies show larger amounts of substances related to neuronal metabolism, suggesting more active use of, for example, auditory cortical areas.[11]

Gray matter is not the only changing element of brain tissue in musicians. Changes in white matter have also been observed. Studies show greater anisotropy, suggesting either a larger number of fibers, more myelin as insulation around the fibers, or both. Such findings have been observed in corticocortical connections but also in corticomuscular connections in musicians compared with nonmusicians.[12] Musicians seem to have larger corpus callosa,[13] especially male musicians,[14] compared with nonmusicians, indicating more and/or thicker neuronal tracts between the left and right motor and somatosensory areas. Such structural differences are likely related to many types of functional differences, even in the resting brains of musicians compared with nonmusicians.[15] Such structural changes, observed across a wide range of types of studies, speak for the replicability and generalizability of these findings.

The changes in musicians' brains might not be such an inspiration for the educational or therapeutic use of music on their own, since there is no way of knowing how long it has taken for the musician's brain to develop into its adult capacity or even to be sure that all differences are due to changes related to musical training (see below for more detailed discussion). For this reason, follow-up studies and intervention studies become critical. These studies investigate neural changes that are observed in children or adults soon after the onset of musical training to reveal the effects of training. The longitudinal studies showing neural data from before and after musical training have the capacity to characterize such effects in detail. Especially important are data from individuals who are randomized into groups, since such studies are less contaminated by genetic or socioeconomic biases (see below for more detailed discussion). They generally confirm that making music can increase brain plasticity and that the effects of music are positive and observed in large areas both in gray and white matter. These studies alone could inspire the use of musical training and some of its elements as a starting point for educational, therapeutic, and ameliorating activities.

Functional differences between musicians and nonmusicians, or functional changes due to musical training, can be divided into two main categories focused on two adjacent levels of processing. Some studies highlight differences in the very basic cortical and subcortical processing, such as in the latencies and amplitudes of early responses to any sounds, musical sounds, or language-related sounds. For example, the fidelity of the brain stem responses in conveying the temporal and frequency information present in sounds has been shown to be higher in musicians,[16] and, importantly, such fidelity increases via musical training within 1 year in children.[17] Such low-level changes may have an extremely strong impact on further processing, since the ability of the cochlea and the brain stem to replicate the content of a sound and to deliver it undistorted to the cortical processes forms the basis of all sound processing in the brain, providing better performance in listening to speech in noise or hearing masked sounds.[18–20]

Higher level functional differences between musicians and nonmusicians, however, are harder to interpret, since some simple tasks show less activity in musicians,[21] while some tasks show more brain activity in musicians.[6,22–24] Here, the distinction might be between the levels of the automatization of the processes under interest: simple motoric tasks tend to get automatized, thus involving fewer neural resources, while more complex (including auditory) tasks require more resources. This seems to occur even if the perceptual accuracy in the task is matched.[25]

Taken together, these findings indicate that learning to play a musical instrument or to sing imprints in the brain structure and function and that these effects may be extremely beneficial for ameliorating, training, and educating the auditory system for a wide variety of tasks—even tasks unrelated to music.

Challenges faced by the auditory system: when extra processing capacity is useful

The auditory system is faced by huge challenges in our everyday lives. Our environment is full of situations where we need to segregate sounds into streams and where several sound sources are present at once.[26] Likewise, we need to differentiate relevant and irrelevant sounds from each other. Efficient activity of the auditory system is based on both low- and high-level cognitive skills. Beginning in the cochlea, information on the acoustic characteristics of a sound is presented, both in the form of frequency filters and as temporal firing patterns related to the phase of the oscillations. Thereafter, the information is processed using multiple time- and frequency-domain processes when it progresses to higher levels in the auditory system. Increase in accuracy and fidelity is obtained by continuous activity of ascending and descending pathways, and this requires learning of auditory scene analysis via exposure.[26]

Higher level cognitive skills related to memory, attention, and predictive processes are essential to making sense of the auditory input. In auditory cognitive neuroscience and in more traditional hearing skill research, the role of such learning processes has proven to be vital in auditory tasks like speech perception; segregation of sounds into streams, such as when listening to speech in noise; perception of music; learning native and nonnative languages; and spatial perception in complex auditory environments.

Language learning places specific requirements on the auditory system. Comprehension of native language stress patterns helps in segregating continuous streams of syllables into words, and such ability is observed already at birth.[27] Memory traces of auditory experiences of speech and music even from before birth are available in the neonatal brain[28,29] and may help the brain make sense of the auditory scene right after birth. The set of native language phonemes needs to be quickly and effectively recognized, and, for this, a map of these phonemes is constructed during the first 12 months of life.[30] Without the map of native phonemes that includes a prototype of each phoneme, the perception of language would be inadequately slow. Listening to and comprehending spoken language is a very demanding task computationally, especially when speech is presented among noise.

When the auditory system is not supplied with the full acoustic input, as in the case of congenital deafness or hearing deficits, the development of the skills related to auditory feature detection and sense making is compromised. A cochlear implant is not capable of delivering all auditory information to the cochlea—rather, the input is a very small and distorted fraction of all available sound information, which affects the communication development of cochlear implant users, especially depending on the age of implantation.[31,32] In the case of hearing aids, some information is lost, although the situation is far better than with cochlear implants. In users of cochlear implants and hearing aids, there is an even higher demand for central auditory processing capacities and a great need for learning in order for the individual to be able to perceive sounds efficiently.

Prematurity, even without any insults to the brain, affects brain development and is associated with an increased risk for language and learning difficulties.[33,34] We and others have proposed that the early auditory environment within the intensive care unit and during later hospitalization might play a role in the decreased auditory, attentive, and learning skills of prematurely born infants.[35] These infants would need support to develop adequate skills for sound discrimination and analysis.

Dyslexia and other language impairments are associated with minor deficits in the auditory system, observed with brain measures in infancy, well before any reading or writing skills can be assessed.[36] Even though dyslexia manifests in reading and writing, differences in auditory neural processes in children and adults with dyslexia have been demonstrated,[37,38] and, due to the genetic component of dyslexia, infants of dyslexic parents show some minor differences in auditory processing compared with infants of parents without dyslexia. Infants with dyslexic parents and children with symptoms of dyslexia might benefit from training their auditory systems to overcome the possible differences in auditory processing early in life. In fact, evidence for music-based training effects in dyslexia has already been obtained.[39–41]

In addition, infants with several other developmental conditions and syndromes have been shown to have atypical auditory processing. These include autism spectrum disorders (atypical reactions to variations in speech sounds[42–44]), attention deficits,[45] and cleft-palate,[46] as well as children with cochlear implants.[47,48]

In summary, several situations in all of our everyday lives and in the lives of individuals with different types of hearing deficits and other conditions require high amounts of processing capacity from the auditory system. Since individuals with musical training seem to have gained more processing capacity in terms of the number of neurons and the number of connections between neurons, the question of the usefulness of music-based training on gaining such processing capacity is raised.

Music-based training and auditory processing capacity

Theoretically, differences between musicians' and nonmusicians' brains could be due to three main causes. First, innate differences could be present in individuals who later become musicians or nonmusicians. Such differences could be present already at birth or appear at any stage of development due to genetic programming. Second, purely training-related changes could materialize in the brains of musicians as the results of hours and years of practicing music. Third, there could be a complex genetic inclination toward musicianship and musical training. This could include genetic predispositions toward easier learning of music, more reward obtained from learning music, more neural changes occurring through musical practicing, and invisible predispositions toward several aspects of careers in music that could also include environmental factors like socioeconomic factors, musicians, and other artists in the family.

Here, and more generally for the evidence-based design of music education for infants and children, the most important contributing factor from the list above is the purely training-related changes. Namely, those are the effects that every infant and child could benefit from, regardless of their genetic, socioeconomic, or other background. Importantly, such a position does not require us to suggest that the other potential causes are nonexistent or meaningless causes of differences in professional musicians' brains or capabilities. We simply choose to investigate the second cause for the purpose of evaluating the magnitude and type of effects that training can have in wide educational and societal contexts.

In order to estimate how much of the neural differences observed in musicians are caused by musical training or are innate, cross-sectional comparisons between musicians and nonmusicians (or children with and without musical training) must be replaced by longitudinal studies, as mentioned above. Longitudinal follow-up studies in musically active children can help follow their musical, auditory, and neural development during the course of training.[49–51] In these studies, the participants would be children with music as a hobby and children with other hobbies unrelated to music.

Hyde *et al.* investigated 5- to 6-year-old children before and after 15-month training.[49] They showed that the children in the one-on-one music training group had structural changes in their frontal, temporal, and parietooccipital brain areas—importantly overlapping with comparison studies between musicians and nonmusicians. Moreover, they also showed that these changes correlated significantly with improvement in auditory and motor tasks, thus providing strong evidence of effects of training. It is noteworthy that, in their study, control children were also given music lessons; however, they were given in a group setting and were not focused on learning to play one single instrument.

In a similar vein, we investigated longitudinal brain development in children starting a musical hobby in several stimulation paradigms, enabling us to determine how the auditory brain areas react to changes in regular sound streams or in melodies.[50,51] In the first recordings at the age of 7 years, when most of the children in the music group had just started their training or were about to start, we found no group differences in the brain responses compared with children of the same age starting other hobbies. However, 2 years later and beyond, the MMN and P3a brain responses had grown in the music group, while no such development was observed in the brain responses of the control group. The initial similarity in the brain responses and their subsequent growth due to musical training suggests that the enhanced reactivity of the auditory cortex originally observed by Pantev and his group[9] in adult musicians is indeed caused by music training and is not innate. When we used a more complex paradigm including short melodies, this reactivity developed more slowly and with varying time courses for different sound features, such as pitch and timbre.

Randomization into groups that start musical or other training enables researchers to study how training started from the initiative of others (teachers and researchers) and not by the family themselves (parents or child) can affect neural development. Such studies are rare but important, since they provide the best way to overcome pre-existing differences like interest in music or socioeconomic differences (yet even these studies are not free from such effects, see below). Thus, longitudinal studies also allow for testing the causality of the neurocognitive effects of music training. Moreno *et al.*[52] and Chobert *et al.*[53] randomized children into groups who received musical training or painting training for 6[52] and 12 months, respectively.[53] Importantly, these two studies were able to confirm that musical training resulted in neural changes in sound processing, both in music and speech, and, further, that these changes were also reflected in the reading skills of the children after training.[52] Trainor *et al.*[54] report similar neural-level changes in infants randomized to receive musical classes.

Summary of types of music-based training

Most studies presented above are studies of individuals learning to play classical music with a musical instrument. This is understandable, since this group of individuals is numerous and their training is highly uniform in terms of practice methods. When comparing individuals with and without such classical training in a musical instrument, the differences at the neural level are clear (see above). Clear effects and significant findings may be due to both large effect sizes and small interindividual differences because of similar training and extensive amounts of training. Even though the effects are clear, these findings do not, however, prove that learning to play classical music with a musical instrument would be the strongest and most effective way to ameliorate and train the auditory system in children, and it is not applicable to infants. For this reason, it is important to compare the types of training that have been used in musical training studies.

Musical playschools provide group musical play according to a clear learning plan but with an emphasis on positive emotions and personal interest as a driving force of learning. The learning takes place in a small group of children sometimes accompanied by their parent(s), and the methods in musical playschools comprises singing, dancing, learning to play several musical instruments, and other musical activities, like drawing to music. Musical playschool pedagogy is aimed at starting and strengthening a love for music via activities that invite the child to be active in the world of music, song, and musical instruments. Several studies mentioned above have shown neural-level changes in children participating in such activities. For example, Moreno *et al.*,[52] Putkinen *et al.*,[55] and Chobert *et al.*[53] were able to show both neural and behavioral changes after such musical play in a group. In enhancing the auditory skills of children with dyslexia, such musical playschool has been shown to be effective.[39,40] Such activities have been shown to be especially effective in improving speech-related skills in children with cochlear implants.[47,48] Even though group activities do not allow the teacher to pay specific attention to each child and his/her musical development, musical playschool may offer other benefits. Specifically, learning with other children may be more beneficial than learning alone owing to a more efficient use of mirror neurons in learning—especially in children with cochlear implants participating in musical playschool with their normal-hearing siblings. Emotional and social aspects of the group in musical playschool may also have a large effect on learning outcomes when the group provides a positive and inspiring learning atmosphere.

The role of informal musical activities resulting in neuroscientifically proven effects is an interesting one. Informal musical activities may involve the child singing on his/her own, without input or encouragement from others, humming to musical tunes, dancing, listening to music, using environmental affordances as percussion instruments, and other types of active engagement with musical material without instruction. Such activities are hard to document and difficult to measure, but studies have done so and found neural-level determinants of such activities. Effects of informal musical activities have been shown both at behavioral and neural levels.[55–57] Informal musical activities are often observed in conjunction with formal training: a child who takes part in musical playschool 1 h per week may spend large amounts of time singing, humming, drumming, and dancing to the same melodies from the musical playschool. Such combinations of instruction and informal activities are especially hard to document. Informal learning is completely learner-paced, learner-initiated (even though environmental affordances may have large effects on informal activities), and oriented according to the learner's own areas of interest. Such factors may play a crucial role in accelerating learning in informal situations. It should be noted that informal musical learning is not always solitary; infants often initiate such learning events by inviting parents or siblings to take part, while schoolchildren learn together in unofficial settings, like garage bands.

Interestingly, self-paced and self-initiated learning also sometimes results in professional musicianship. In such cases, both neural and behavioral differences between self-trained (rock and folk) musicians, classical and jazz musicians, and nonmusicians are evident,[57–63] highlighting the complex influences of genre- and training-specific effects on the brain. Even if predispositions in choosing a given genre on the basis of sensitivity profiles in auditory processing cannot be ruled out in these cross-sectional paradigms with adult participants, these findings suggest that the type of musical expertise can be highly accurately reflected in the brain and, further, that formal music training (e.g., in terms of score-reading skills) is not necessary for neuroplastic changes to occur. Actually, musicianship is not a requirement for such tuning of auditory perception at all: listeners with a preference for listening to heavy metal versus Latin American music displayed different cognitive event-related potentials[64] during attentive listening to these genres.

All in all, on the basis of the studies mentioned above, the following factors of music-based amelioration and training can be proposed to enhance learning and auditory neurocognition: (1) sufficient amount of training, (2) high personal motivation to practice and reward from practicing, (3) group activities supporting learning, (4) combining both formal and informal learning methods, and (5) individual learning schemes taking into account the learner's specific interests.

Such learning methods are naturally highly dependent on the age of the learner. In very young learners, learning by mere exposure is still effective,[28,29,56,57] and exposure during the early years and months may provide a basis for later learning.[65] Yet, in most studies, by the age of 12 months, active participation in learning produces the most effective results.[66] In sum, finding the best, most motivating, most suitable, and most effective music-based training method for each infant and child remains a pedagogical challenge.

Critical view on amelioration and training studies

The first challenge for music training studies comes from the various alternatives in research paradigms. If the experimental tradition of life sciences (e.g., with animal models) is followed, then in music studies the participants should also ideally be randomized into different intervention groups. Additionally, a control group should be recruited, either as a passive or (preferably) active control, or, alternatively, using a waiting-list principle in which the control group is given the musical training (e.g., during the following semester) after the data collection. However, these two principles of randomization and optimal control groups are very hard to maintain in any longer scale follow-up study. The likelihood of drop-outs is already relatively high for interventions of a few weeks when participants' group assignments are based on (pseudo)randomization (e.g., 20% in Janus *et al.*[67] in 20 days; over 30% in Chobert *et al.*[53] in 2 years). If this is compared with the drop-outs in studies using participants based on their self-selected hobbies, the benefits of the self-selection are evident: during a follow-up project by Putkinen and colleagues, the great majority of the children participated in the data collection several times during the 14 years since the commencement of the project (Putkinen, 2017, oral communication). However, it should not be ignored that, in Putkinen's project, a number of subjects also declined to participate in one or more recordings, particularly in the control group (children and adolescents with hobbies unrelated to music), making statistical analyses of the time-series data of the neurocognitive indices highly demanding. The issue of diverse socioeconomic statuses between groups is less of an issue: based on the background information given by the families, there were no systematic differences in parental education or income between the groups.

Another challenge to the development of the field and the implications of musical training studies is introduced by the demand to always publish something novel and, in the great majority of cases, something novel with positive results. This implies that replications of already used training paradigms are not favored by researchers. Likewise, the lack of positive results also often prevents the research outcome from being published. In our field, this bias in publishing is creating a situation in which it is likely that a plenitude of experimental evidence remains unpublished owing to negative (null) findings. The solution for this challenge might be found by making compromises in experimental designs—if feasible, both old and new paradigms could be used in a single study. Most likely, replications of the paradigms will not provide one-to-one replications of the original results. This lack of replicability should, however, not be considered to abolish the significance of the original findings but instead might reflect, for example, the differences in musical educational principles in the intervention or in society more generally, or even the differences in educational principles in all school practices.

Conclusions

We have discussed the effects of music-based amelioration and training of the auditory system in infancy and childhood. Such training is beneficial generally and is especially important in some cases, such as dyslexia, learning and language disabilities, hearing problems, and other disadvantaged conditions. The field is advancing rapidly, and we are gaining more and more insight into which types of training methods could be most effective and who the training specifically helps. Unfortunately, as in all science, the field is also affected by biases and issues in the studies that make the results less generalizable or even less reliable. Our hope is that raising these issues will advance the field and make future studies better. All in all, we urgently need information on the effects of music-based training for the advancement of auditory skills.

Competing interests

The authors declare no competing interests.

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